

Timber Productivity Research Gaps for Extensive Forest Management

Lloyd C. Irland

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Abstract On extensive areas of small scale forests, significant opportunities for improving the value of future timber harvests while also improving other resource values are now being missed. A new focus on practical extensive management research is needed, especially as implementation of intensive practices has been declining in many areas, and new “close to nature” prescriptions are coming into more widespread use. This paper offers an extended definition of management intensity, and then discusses general research needs in regeneration, pest management, stand management guides, financial analysis, and nontimber values, and effects on ecosystem services. In this scheme, intensity is not directly related to management emphasis. In this study, research needs were assessed for timber productivity in four forest type groups in the Eastern USA: loblolly-slash pine, white red jack pine, northern hardwoods, and oak hickory in the North (details are given in Supplementary materials on SSFO website). Based on this preliminary assessment, general areas of research needs seem remarkably similar across all four types discussed. Further, it is likely that similar issues and needs occur in many parts of the world on small scale forest ownerships. Naturally their specific nature and importance will vary widely. Yet in most cases, preparing and updating existing guidelines and financial and silvicultural analyses, plus selective remeasurements of past long-term experiments, will likely prove important.

Keywords Research needs · Extensive management · White-red-jack pine · Northern hardwoods · Oak-hickory · Loblolly-slash pine · Eastern USA

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L. C. Irland (✉)
The Irland Group and Yale University, 174 Lord Road, Wayne, ME 04284, USA
e-mail: lcirland@gmail.com

Within the forestry community, much time has been spent debating the rationale for adopting the most intensive management regimes. The major opportunities for upgrading management from custodial to extensive have received less attention. But timber productivity, as well as environmental, economic, and social goals can be advanced by expanding extensive management on lands now receiving little management at all. The definition of “productivity” may be somewhat different on extensively managed lands, however. For good reasons, intensive management, especially in softwoods, often has a strong focus on volume growth. In extensive management, the principal concern is to upgrade value growth compared to current non-management (Irland 1998). Further, the concern is often with existing stands instead of bare land.

The motivation for discussing this issue arises in 3 ways. From the *landowner* standpoint, the question is to what degree upgraded management is financially attractive and consistent with other ownership goals. We will note some disadvantages of purely custodial management below. For the processing *industry*, the concern is to see expanding raw material supplies, of increasing quality, in the future. Not only that, but initial treatments will yield pulpwood and biomass supplies that mills will need as the economy improves. Communities and local areas may not be entirely indifferent to this issue.

From *society's* standpoint, it may be seen as old-fashioned in some quarters to think of improved forest management as a good thing in itself, but there are other issues. Early increases in supply of fuelwood and biomass can contribute to at least local energy self-sufficiency and in some places to cost savings for energy users. Social benefits from more widespread management for quality will necessarily emerge slowly, as we do not anticipate an immediate rush by large numbers of landowners to adopt better management practice. Benefits in terms of improved quality wood supply will arise over generations and not years. Slow changes like this will not generate dramatic and early local or national economic impacts.

The number of landowners likely to have an immediate interest in shifting from custodial management to extensive practice for financial reasons may be small. They are likely to be concentrated in the size classes from 100 to 500 acres, though this likely would vary regionally and by markets and site class. Interest in managing forests for ecosystem services is increasing. Whether owners are motivated to actively manage for such services, and how their motivation might be increased, and how ecosystem services might be affected are important questions beyond the scope of this paper.

This essay originated in a brief effort to assess research gaps for extensive management for timber productivity in the USA.¹ For this reason, practices aimed primarily at restoration or fuels issues are not considered. While the principal concern here is timber productivity, this objective is closely affected by nontimber concerns and constraints which cannot be ignored. Research for this paper reviewed

¹ Typically a research gaps study performs an extensive survey of foresters and scientists, or convenes a major conference, and may supplement these with an extensive literature review. Resources for such approaches were lacking. Instead, this effort attempts to develop a general approach by use of selective literature review, interviewing, and assessment of regional forest conditions. It could be described as a “desk study”.

four type groups to draw out some general ideas. The initial scope of the assessment covered four forest types in the eastern USA only, yet on reflection it seems that the broad themes are of potential international applicability.²

First, an extended definition of management intensity is offered. This forms a basis for identifying common themes that can define research, assessment, and outreach needs. A series of recommended general issues for research is then outlined, followed by conclusions. This paper is not arguing that there is an immediate crisis calling for crash programs, only that there is a major area of opportunity that needs increased, more focused, and more coordinated attention in the future.

The Spectrum of Management Intensity and Management Emphasis

Smith et al. (1997, 9th ed), describe intensity as a continuum of “the amount of effort expended on the treatment and care of stands” (p. 16). Measures for this continuum include funds invested in stand establishment and cultural treatment, frequency and intensity of cutting during the rotation, and concern accorded to future relative to current returns. It also implicitly refers to quality and quantity of wood yield and to financial returns. The *Dictionary of Forestry* offers somewhat more detail (box).

“*Intensive forestry*. The practice of forestry to obtain a high level of volume and quality of outturn per unit area through the application of the best techniques of silviculture and management—*note* compared with extensive forestry, intensive forestry requires greater inputs of labor and capital in terms of quantity, quality, or frequency.”

“*Extensive forestry*. The practice of forestry on a basis of low operating and investment costs per acre.”

Source: Helms (1998, p. 61, 98).

Identifying intensive management with “best” practice seems gratuitous, as intensive practice is simply not warranted in many situations (Irland 1983). There are many examples of excellent forest practice at low and moderate levels of intensity. Competent extensive management also requires application of best techniques, experience, and judgment, supplemented by diligent supervision of marking and harvesting. Management intensity can be understood not only at stand level but at landscape level. How much of an entire landscape is intensively managed? While the field of *landscape ecology* is increasingly important, this paper will focus on the stand level only.

The continuum Extensive-Intensive does not necessarily relate closely to management emphasis. Intensity is usually associated with objectives of increasing timber production and financial returns. Yet management may be intensive in

² A larger issue, with particular importance for certain areas, is the potential for climate change to affect managed natural forests. While this issue must be born in mind, it cannot be handled here (Anon 2009). Likewise the question of carbon sequestration as affected by management is left aside here.

Table 1 Continuum of management intensities versus management emphasis—schematic outline

Mgt Goal → Intensity	Preservation or natural process management	Restoration of some desired condition	Cover costs and taxes	Income generation Immediate	Income long- term	Maximize return on Investment	Maximize timber volume production	Maximize aesthetic, habitat, water or other benefits
Exploitive				XXX				
Custodial	XXX		XXX*					XXX
Cut/Let Grow			XXX	XXX	XXX			
Low Intensity			XXX		XXX	XXX		XXX
Moderate Intensity			XXX		XXX	XXX	XXX	XXX
High Intensity		XXX			XXX	XXX**	XXX	XXX

This table is intended to offer a general overview, not to serve as an exhaustive and precise means of classifying all possible regimes. Differences of opinion will no doubt arise about the finer distinctions implied here

* Custodial may cover costs under favorable conditions

** A conjecture is that this applies only to the loblolly shortleaf resource, not to the others considered here. Perhaps that conjecture should be subjected to serious testing under current and likely future market conditions, following the approach of Yin and Sedjo (2001)

pursuit of other goals (Table 1). In this approach, the term “extensive management” is an elastic one that can be used in regional, site- and situation-specific ways. There is no need for a uniform national definition.

Table 1 describes one way to elaborate such a continuum. Intensity moves from purely *exploitive*, which may include immediate subdivision and sale, all the way to long-term high intensity management. *Custodial* would be confined to administration and protection, with occasional salvage as required; cut/let grow would include programs of cutting with no other treatments. Typically there would be no specific plans for harvesting. *Low intensity* management might include infill planting, improvement cuts, and occasional light partial cuts. Some expectation of periodic incomes is likely. *High intensity* might include the full array of practices aimed at maximizing timber growth. Sustained yield is not noted; it is implicit in all intensities above exploitive, and is not relevant to the emphases for preservation or for maximizing nontimber benefits.

Purely exploitive practice occurs everywhere at some level. Especially when current stand conditions are poor, and land markets are active, owners can make money by stripping the land and selling it. This paper is not concerned with comparing profitability of exploitive practice with longer term custodial management.

This view would consider regimes using multiple precommercial thinnings or cleanings, routine mechanical or chemical site preparation, or all-aged/selection silviculture to be intensive. Also, fuel reduction projects are intensive due to their high cost and skill intensity, as are most restoration projects (Jenkins et al. 2004). Also, particular practices generally seen as intensive may play an important role in extensive regimes. The terms “intensive” or “extensive” can be taken as a characteristic of a planned management regime over the life of a stand, and not just of particular practices.

No clear cutoff point separates Intensive regimes from Extensive ones. It is useful to think of Extensive management as any level of practice between what is considered Custodial and what is considered Intensive in a given region. Custodial is more intensive than exploitive management; likewise, extensive management is more intensive than custodial. Generally speaking, extensive management has to do with managing existing, natural stands instead of creating brand new ones on bare soil. Interesting exceptions exist, as we shall see. We can depict several broad contrasts between the ends of the spectrum of intensive versus extensive management. Note that there are many exceptions and these are matters of general emphasis only:

	Intensive	Extensive
Rotations	Shorter	Longer
Management emphasis	Volume growth or financial	Value growth; nontimber
Yield expectations	High	Modest to low
Sites used	High, favorable terrain/access	Less favorable sites
Stand Composition	Single species	Mixtures
Structure	Even aged, or selection	Multiple ages or layer-cake
Yield prediction	Computer models	Informal methods

Economists think of “the extensive margin” as the zone beyond which management of any kind does not pay. The most intensive practices are likely to be attractive to landowners on the higher sites, and may be financially unwarranted on the lowest sites. Due to access, slopes, or other factors, there are areas where management of any kind does not pay its way. *Management intensity is not a question of virtue. Higher intensity is not always “better” or wiser, nor is lower intensity management always more virtuous.*

Some Advantages of Extensive Management

Schulte and Buorngiorno (1998) noted a series of advantages of uneven aged management of loblolly pine. This list (paraphrased here) can be considered suitable for extensive management in general:

1. Proven track record
2. High sawtimber yields
3. Can be financially preferable to even-aged management under some conditions
4. More profitable for contractors
5. Ability to rehabilitate understocked stands
6. Lower capital outlay
7. Periodic cash flow
8. Diverse stand structure
9. Better adapted to steep and fragile soils
10. As a result, less likely to be disruptive of natural processes

These advantages do not apply in all situations. They may be offset by several disadvantages, including difficulty of achieving regeneration or keeping hardwoods out of softwood stands, and higher amounts of capital exposed to risk. *The point is simply that a positive case can be made for extensive management that does not rely solely on negative arguments such as the low profitability of intensive practices on low sites.*

Many owners, for whatever reasons, will not adopt higher intensities of management. Further, there are owners now managing intensively who may be compelled to trim their efforts during the present period of low prices and production volumes. But a great opportunity for timber productivity lies before us with the large areas, in many continents, that could potentially be brought from largely unmanaged conditions to some level of extensive management.

Research Needs Related to Management Problems

The productivity opportunity has to do with showing landowners and managers the benefits of adopting extensive management programs instead of continuing with unplanned or haphazard approaches. Several important research areas appear regularly. Specific problems and how they would best be addressed by research will vary widely by type and region, but several common themes emerge. These are

briefly noted in the following general categories: regeneration, pest management and prevention, stand management guides, managing damaged stands, financial analysis and outreach, nontimber values, and ecosystem services impacts.

Regeneration

Custodial management may not always yield desired natural regeneration. In some circumstances, especially on lower sites, the economics may favor natural regeneration and more patient yield and rotation expectations. Further, natural regeneration may fit well with emerging guidelines for protecting ecosystem structure and function. Practical experience with natural regeneration is abundant; best practices can readily be formulated. Existing management guides often summarize this well; they may merely need updating. A systematic exploration of the issues with scientists and experienced managers can yield focused priorities for further analysis or outreach. This would be especially helpful for hardwood planting. Infill planting or underplanting will be desirable in some situations; this practice seems in its infancy in most areas and could benefit from well designed research trials and reviews of field performance. Stubborn understories of undesired vegetation are common, often worsened by light partial cuttings (Boyce 2009).

Pest Management and Prevention

In some forest types, moving from custodial to extensive management could be a major aid to maintaining stand vigor and thereby reducing vulnerability to a range of pests. At the same time, some management practices can make pest problems worse. Better guides for managing entire forest types to balance these competing effects are needed. Practice is highly developed concerning the southern pine beetle (Nowak et al. 2008, p. 261). Ways project and mitigate the impacts, and ensure that yield expectations are realistic are needed. The list is so long that setting research priorities seems impossible.

Advising landowners to consider moving from custodial to extensive management will involve effort and commitments. To help them make decisions concerning growing stock levels and risk issues, a better concordance of climatologies and insects and disease knowledge would aid managers in risk ratings for the full suite of risks—ice, wind, insects, and diseases (e.g. Irland 2000). To date, separate assessments of individual risk factors have not enabled managers to gain a comprehensive view of risks. The pest management issues involved in extensive management may differ materially from those in intensive management (see, e.g. Schowalter 2008).

Stand Management Guides—Quality and Volume

A large volume of research and applied work gives guidance on the major issues in stocking level control and stand management, e.g. for scheduling thinnings.³ New

³ For examples, see Leak et al. (1987); Palik et al. 2005; Gilmore and Palik (2006).

issues in extensive management will include: maintaining emergent trees and retention of structural features, creating or maintaining mixtures and multilayered stands (Miller and Kochenderfer 1998), and shifting planted stands to extensive management regimes (for example, Fox et al. 2007).

Existing work and modeling can no doubt be adapted to at least first-cut rough analysis of these problems. An important trend is the emerging focus on “crop-tree management” in several of these forest types. This entails pragmatic practices of simply identifying promising trees and giving them growing space. Benefits can be large (for examples, Sendak and Leak 2009; Desmarais and Leak 2005; Page and Smith 1994). Yield prediction, especially for mixtures and multilayered stands, is a major need across all types considered here. Progress on yield prediction tools will help support development of guidelines and will aid owners and consultants who wish to make their own predictions. Improvements in yield prediction were critical to the adoption of major programs of highly intensive management; the same could be true for more extensive management regimes.

Success in extensive management will likely involve selective use of specific practices, such as fertilization, site preparation, infill or underplanting, and selective use of chemicals for insects, disease, animal damage control, or vegetation management. Assessment of practical experience and targeted development and application work would seem warranted.

Managing Badly Managed or Damaged Stands

The management history in many regions of the world has depleted many stands of valuable growing stock and left behind a series of obstacles to improved management. The ongoing impacts of weather events have also had their effects, including results of poorly controlled salvage efforts. Drawing on experience to develop and pilot test working guides for stand restoration ought to be a high priority. Managers often face a “triage” situation—they need to decide if a stand can be saved by treatment, if it needs attention at all, or if it should be cut and replaced. General triage guides—especially for low-site or damaged stands, or stands plainly in the path of invasive agents—are needed. They need to be built up from practical experience as well as ongoing research. They will need to be tailored to site, terrain, visual objectives, and riparian considerations and designed in a landscape context.

Financial Analysis

Just as intensive management is not profitable or suitable for all landowners in all times and places, the same applies to upgrading from custodial to extensive management.

Improved, locally relevant, practical financial analysis of extensive management practices and regimes would be most useful. A full range of tools ranging from straightforward Net Present Value analyses of individual practices, to simulations and linear programming models analyzing sequences of treatments could be used (Pelkki and Kirillov 2004; Buorngiorno et al. 2004). As a great deal has been done,

necessarily relying on simulations and projected yields, validation takes on great importance (e.g. Ledoux and Whitman 2006). Simple methods are often adequate; complex optimizing models can certainly yield insight but may be costly to employ. Many existing studies are useful but deal with only a single practice, not with entire regimes over the life of a stand.

On the lower range of site quality, extensive management can be financially competitive with intensive management (see, e.g. Chang 1990). Short rotation intensive regimes often produce wood for commodities measured in tons; one or two broad categories suffice to capture value differences, and premia for large logs may be low or absent. Financial analysis of extensive management options is more difficult. Extensive management will involve multiple species, complex stand structures, and more complex wood valuation relationships.

This essay advocates that wider emphasis on growing for quality species and stems, in extensive management regimes, is desirable. Will increased supply of higher grade logs affect prices? In most markets, price premiums for log size and grade are wide. They are not likely to be affected very much by the modest and slow increases in supply generated by expanded extensive management. A rapid spread of improved management is not likely, especially as the whole argument of this paper is that the information base for such expansion is so weak. Also, we know that many owners are not motivated to shift from custodial practices. There is, then, no material risk that expanded extensive management will cause prices to decline noticeably by boosting supplies.

In each forest type, past silvicultural and economic studies should be updated and re-analyzed using current markets and prices. Through such a program, valuable past studies, now considered “out of date,” can live again and provide considerable benefit to land managers.⁴ Case studies of actual managed properties, if they can be obtained, are the most effective way to show landowners and their advisers the financial aspects of management. As extended rotations and “Big Tree” prescriptions, and “close to Nature” forestry practices become more in vogue, there is increasing need to understand financial and other implications.

Nontimber Management Constraints and Regulations

In responding to concerns about oversimplifying ecosystems and retaining elements of structure in harvest units, land managers have adopted a range of prescriptions designed to reduce the effects of timber harvesting. This has been especially true on public lands. On private lands, some measures, especially stream protection buffers and red cockaded woodpecker areas, have been imposed by regulation. Potential effects on longterm soil productivity have received much attention, for example Grigal (2000).

Some of these constraints may cost little; others much. Evaluations should be conducted to determine to what degree they are working as intended, and what costs

⁴ An excellent example is Sendak and Leak, 2009, who updated previous studies. It may be noted in passing, though, that many publications do not supply enough basic information to allow later workers to update their analyses.

they incur (see, e.g. Fox et al. 2007; Ledoux and Whitman 2006). If we are to ask landowners to undertake expanded extensive management, they are going to be sharing some of their modest yield gains with these constraints. It is critical to make sure the benefits are real. Many studies look only at stand level analysis and not at the level of an entire property, which may miss important cumulative impacts on production and financial returns.

Concluding Remarks

Millions of acres of small-scale forest ownerships worldwide are producing occasional low yields of low value wood when they could be yielding far higher percentages of valuable logs—if only they were well managed. Even worse, in many areas they are serving as nurseries for harmful invasives. Opportunities to upgrade value yield by adopting extensive practice on forests currently receiving little management attention are surely large. This paper is primarily concerned with timber production, but planned extensive management can also support a number of different management goals.

To persuade owners to upgrade management from custodial (or worse) to planned extensive management, a positive case must be made. This case is easy to make. But without a better research base, on a number of key topics, it will remain a series of abstractions. One can only imagine what could be achieved on currently under-managed lands if extensive management were to receive the same kind of sustained and aggressive effort that has been devoted to southern pine intensive management, as ably described by Fox et al. (2007) and Jokela et al. 2010. Especially because extensive management often entails long rotations, our long-term research studies are an irreplaceable resource. All efforts must be made to ensure that their potential for future learning is not lost (Irland et al. 2006).

Before specific research priorities can be set, for each region and forest type, an extensive effort to compile what is already known, including administrative studies and privately held measurements, would be sensible. This should be focused regionally and on individual forest types to be most effective. Such exercises can take stock of what is known and produce valuable updates of guidelines and other decision tools, as well as substantial monographic treatments. Following this, some targeted follow-up measurements on the most interesting examples of managed stands may be desirable. General arguments of this essay cannot be treated as conclusions but rather as starting points for stimulating discussion.

For many small scale private owners, extensive management may offer attractive strategies for upgrading forest productivity in cost effective ways while maintaining forest cover and amenity values that are important to them. The best point on a continuum of intensive to extensive management is to be decided based on landowner objectives and constraints. It is not a black or white matter, nor is it a question of virtue or the lack of it. It does seem possible that adaptation to changing climate regimes may be facilitated in many instances by moving from custodial to extensive management.

The potential opportunities to improve forest productivity at all points of the intensity spectrum are large. On the extensive end of the spectrum, productivity will usually mean higher output of higher value products, and not simply more tons per acre. By improving our ability to clearly demonstrate where benefits can be demonstrated of moving from absence of management to extensive management, productivity improvements on large areas are potentially possible. It is time to give due attention to the opportunities before us in extensive practice, and in particular, the chance to bring millions of acres of poorly managed land under planned forest management.

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References

- Anon (2009) NE forests 2100: synthesis of climate change impacts on forests of the Northeastern US and Eastern Canada. *Can J For Res* 39(2):199–487
- Boyce RL (2009) Invasive shrubs and forest tree regeneration. *Jour Sust For* 28(1–2):152–217
- Buorngiorno J, Schulte B, K Skog (2004) Quantifying trade-offs between economic and ecological objectives in uneven-aged mixed-species forests in the Southern US. US Forest Service Gen Tech Rep FPL-GTR-145
- Chang SJ (1990) An economic comparison of even-aged and uneven-aged management of southern pine in the Mid-south. Presented at SOFEW 1990 spring workshop, Monroe LA
- Desmarais KM, Leak WB (2005) Ten year performance of eastern white pine under a crop tree releases regime on an outwash site. *Nor Jour Appl For* 22(2):1399–1400
- Fox TR, Jokela EJ, Allen HL (2007) The development of southern pine plantation silviculture in the Southern United States. *J For* 105(1):337–347
- Fox TR et al. (2007) Alternative silvicultural practices in Appalachian forest ecosystems: implications for species diversity, ecosystem resilience, and commercial timber production. Proceedings, 15th Central Hardwood Conference, US Forest Service S Res Sta GTR-SRS-101, pp 276–280
- Gilmore DW, Palik B (2006) Red pine management guide. http://www.ncrs.fs.fed.us/fmg/rp/docs/rp_hlth.pdf. Accessed 5 May 2009
- Grigal DF (2000) Effects of extensive forest management on soil productivity. *For Ecol Manage* 138:167–185
- Helms JA (ed) (1998) The dictionary of forestry. Society of American Foresters, Washington
- Irland LC (1983) A definition of intensified forestry: characteristics and uses. *The Consultant* 28:(81–84)
- Irland, LC (1998) Growing wood for quality: the Great Lakes Region's comparative advantage. In: Proceedings, Conference on Forest Productivity. Duluth, MN, pp 231–238
- Irland LC (2000) Ice storms and forest impacts. *Sci of Total Environ* 262:231–242
- Irland LC, Camp A, Brissette J, Donohew Z (eds) (2006) Long-term silvicultural and ecological studies: results for science and management. Yale School of F&ES, Global Institute of Sustainable Forestry, Res Pap 005
- Jenkins DH et al (2004) System design and management for restoring Penn's Woods. *J For* 102(3):30–37
- Jokela EJ, Martin TA, Vogel JG (2010) Twenty-five years of intensive management with southern pines: important lessons learned. *J For* 108(10):338–347
- Leak WB, Solomon DS, DeBald PS (1987) Silvicultural guide for northern hardwood types in the Northeast (revised). US Forest Service Res Pap RP NE-603
- Ledoux C, Whitman A (2006) Estimating the capital recovery costs of alternative patch retention treatments on eastern hardwoods. *J For Eng* 17(1):1–7
- Miller GW, Kochenderfer JN (1998) Maintaining species diversity in the central Appalachians. *J For* 96(7):28–33

- Nowak J et al (2008) The southern pine beetle prevention initiative: working for healthier forests. *J For* 106(5):261–267
- Page AC, Smith DM (1994) Returns from unrestricted growth of pruned eastern white pines. *Yale School For Env Stud Bull.* No. 97. 23 pp
- Palik BJ, Kern CC, Mitchell R, Pecot S (2005) Using spatially variable overstory retention to restore structural and compositional complexity in pine ecosystems. In: Peterson CE, Maguire DA (eds) *Balancing ecosystem values: innovative experiments for sustainable forestry. Proceedings, US Forest Service Gen Tech Rep PNW-GTR-635*, pp 285–290
- Pelkki MH, Kirillov NV (2004) Managing mixed species hardwood stands for maximum financial return. In: Yaussy DA, Hix DM, Long RP, Goebel PC (eds). *Proceedings, 14th Central Hardwood Forest Conference. US Forest Service Gen Tech Rep NE-316*, pp 418–426
- Schowalter TD (2008) Insect herbivore responses to management practices in conifer forests in North America. *J Sust For* 26(3):204–222
- Schulte BJ, Buorngiorno J (1998) Effects of uneven-aged silviculture on the stand structure, species composition, and economic returns of loblolly pine stands. *For Ecol Manag* 111(1998):83–101
- Sendak PE, Leak WB (2009) Early crop-tree release and species cleaning in young northern hardwoods: a financial analysis. *US Forest Service Res Pap RS-NRS-6*
- Smith DM et al (1997) *The practice of silviculture: applied forest ecology*. Wiley, New York
- Yin R, Sedjo R (2001) Is this the age of intensive management? A study of loblolly pine on Georgia's Piedmont. *J For* 99(12):10–17